Polymer Effects in 2D Turbulence

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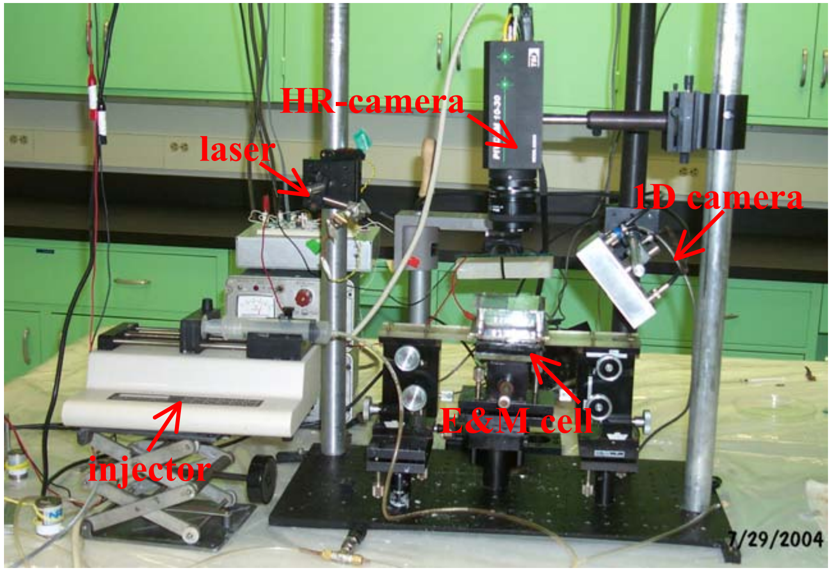
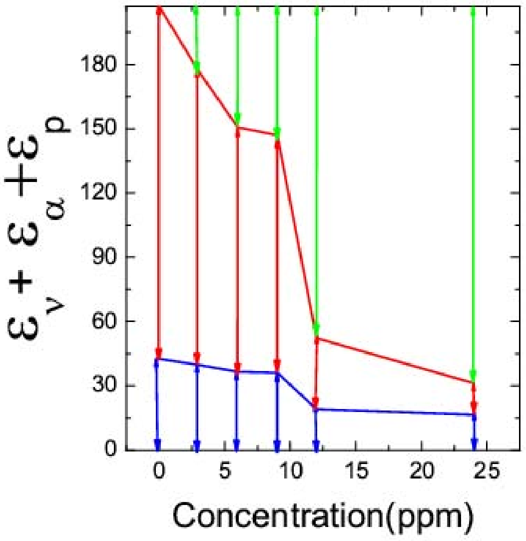
Fluid turbulence is ubiquitous, taking place on many different length scales. Surprisingly, however, by adding trace amounts of polymers with sizes only a tiny fraction of the turbulent scale, the flow behavior can be altered drastically. One of the prominent effects is a significant reduction in the frictional forces in the fluid, known as the polymer drag reduction. To understand such an effect we investigate energy transfer from turbulence to polymers. The phenomenon is not only scientifically interesting but also has a significant impact on technology.



Experimental Setup



The measured energy consumptions by the fluid ε_v (blue), the boundaries ε_α (red), and polymers ε_p (green). The total energy is conserved $\varepsilon_{inj} = \varepsilon_v + \varepsilon_\alpha + \varepsilon_p$. Here ε_{inj} is the energy input. As can be seen, when the polymer concentration increases, more and more energy is taken by polymers.

A unique feature of this experiment is that turbulence is created in a two-dimensional space, i.e., in a freely suspended soap film. The film is enclosed in a glass cell (E&M cell) and driven by an electromagnetic force. To keep the film for a long time so that careful measurements can be made, the film thickness is constantly monitored by a laser and a 1D CCD camera. Small volume of fluid is injected into the film if needed. The pressure on both sides of the film is also regulated by a set of valves (not shown). A small amounts of polymers (PEO, $M_W=8x10^6$) is added to the solution along with small plastic micro-spheres. The high resolution camera (HR camera) tracks the motion of individual spheres and flow velocity at each point in the film can then be calculated. The energy consumptions by various processes presented above were calculated based on the velocity field in the film. Here one observes a sudden change in the polymer energy (green lines) uptake when the polymer concentration is about 10 parts per million. This sudden change of behavior is not expected and is currently under investigation.

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Education:
Three undergraduates (Pedram Roushan, Sarah Rugheimer, and Bernadette Douglass) and two graduate students (Yonggun Jun and Jie Zhang) contributed to this work. Pedram just won a Goldwater scholarship and will continue working on the project. Sarah moved to the University of Calgary. Bernadette is an REU student and will return to Dickinson College this fall. Yunggun and Jie are still working on their Ph.D. theses.

Societal Impact:
Polymers are important industrial materials. Understanding their interactions with liquids and solids are important for engineering novel materials. The ability of quenching turbulence using only a trace amount of polymers can be exploited in applications such as moving liquids efficiently in pipelines and in oil fields. The subject is also attractive for training future scientists.